NAVAL SHIP RESEARCH AND DEVELOPMENT CENTER

ANNAPOLIS DIVISION - ANNAPOLIS, MARYLAND 21402

Stress-Corrosion Studies of Aluminum Alloy 5456-H321 in Seawater

By

George A. Wacker

MARINE ENGINEERING LABORATORY

RESEARCH AND DEVELOPMENT REPORT

July 1967 Report 2436

Report 2436

ABSTRACT

The stress-corrosion susceptibility of Aluminum Alloy 5456 in the H321 temper was investigated as a function of longitudinal, long transverse, and short transverse plate orientations. The alloy was found to be subject to pitting attack but immune to stress-corrosion cracking in flowing seawater at ambient temperature.

Report 2436

ADMINISTRATIVE INFORMATION

This work, which is one phase of an investigation of stress-corrosion behavior of high-strength aluminum alloys, was conducted under Sub-project S-F020 01 02, MEL Assignment 86 114. The report constitutes Fiscal Year Milestone 3 on page A-307 of the May 1967 NSRDC Program Summary, Part II.

TABLE OF CONTENTS

Report 2436

NAVAL SHIP RESEARCH AND DEVELOPMENT CENTER

STRESS-CORROSION STUDIES OF ALUMINUM ALLOY 5456-H321 IN SEAWATER

By
George A. Wacker

INTRODUCTION

Current U. S. Navy interest in corrosion-resistant aluminum alloys stems from a continued emphasis on reducing total ship-construction weight, particularly for surface-vessel superstructure components. Aluminum alloys are finding additional widespread usage in different aspects of naval military construction, such as sonar spheres for deep submergence, helicopter landing pads, radar masts, and small craft personnel carriers. It is quite probable that future programs in hydrofoil and surface-effect craft as well as deep-submergence vehicles will rely on aluminum alloys for certain critical components.

Previous work at this Laboratory[1] and elsewhere has shown that certain wrought heat-treated aluminum alloys are extremely prone to directional variations of stress-corrosion cracking susceptibility in seawater; i.e., stress-corrosion cracking is related to both microstructural characteristics and the plate direction which sustains continuous applied tensile stress. In general, the 5000-series aluminum alloys are known to exhibit excellent marine corrosion properties.[2,3,4,5,6,7] No detailed work is available, however, as to whether or not the stress-corrosion directionality effects observed in the high-strength, wrought, heat-treated aluminum alloys would also pose a problem in the highly cold-worked, nonheat-treatable, 5000-series aluminum alloys.

APPROACH

In order to assess stress-corrosion directionality effects in 5456-H321 alloy, it was decided to expose bent-beam specimens

[1]Superscripts refer to similarly numbered entries in Appendix A.

in seawater utilizing a wide variety of plate orientations to cover microstructural anisotropy effects. A schematic representation of specimen and grain orientations appears in Figure 1.

DESCRIPTION OF MATERIAL

All specimens were machined from commercial 5456-H321 plate (3 inches). The chemical composition and mechanical properties of the plate are as shown in Tables 1 and 2.

Table 1 - Plate Chemical Composition

	Chemical Composition, %										
	Mg	Mn	Cu	Cr	Si	Fe	Zn	Ti	Others Each	Others Total	Al
ASTM Specification B209-64	4.7/5.5	0.5/1.0	0.10 Max	0.05/0.20	Fe + Si = 0.40 Max		0.25 Max	0.20 Max	0.05 Max	0.15 Max	Rem
Actual Analysis	5.18	0.33[1]	0.097	0.075	0.11	0.21	<0.05	0.09	----	0.04	Rem

[1]Low in Mn.
Rem = Remainder, Max = Maximum

Table 2 - Plate Mechanical Properties

Orientation	UTS, ksi	0.2% YS, ksi	Elongation, %
Longitudinal	46.9[1]	29.2	26.5[3]
	50.4[2]	32.3	15.0[3]
Long Transverse	48.4[1]	28.0	19.0[3]
	49.4[2]	28.5	19.0[3]
Short Transverse	42.4	23.9	9.0[4]
	42.6	25.1	8.0[4]

[1]Plate surface
[2]Plate center
[3]2-inch gage
[4]1-inch gage
UTS = Ultimate Tensile Strength
YS = Yield Strength
ksi = Thousand Pounds per Square Inch

METHOD OF INVESTIGATION

Six types of stress-corrosion specimens were used, two for each possible plate orientation, i.e., longitudinal, long transverse, and short transverse (see Figure 1).

Two specimens of each type were tested at stress levels of 0, 50, 70, and 90 percent of the 0.2-percent yield strength (average of longitudinal and long transverse yield strengths). Longitudinal and long transverse specimens measured 7 X 1 3/8 X 1/16 inches, while short transverse specimens measured 3 X 1 3/8 X 1/32 inches. All specimens were stressed to appropriate yield-strength levels as two-point-loaded bent beams and exposed to flowing seawater (1-3 fps)* for 1 year at Harbor Island, North Carolina. Specimens were exposed in the horizontal plane so that sea-water flow was perpendicular to the specimen length. A summary of the test program appears in Table 3.

Table 3 - Test Program

Specimen Type[1]	Plate Orientation	Stress Levels[2] (% of 0.2% YS)
1	Long Transverse	0, 50, 70, & 90
2		
3	Longitudinal	
4		
5	Short Transverse	
6		

[1]See Figure 1.
[2]Two specimens of each specimen type were tested at each stress level; total = 48 specimens.

RESULTS AND DISCUSSION

PLATE MICROSTRUCTURAL CHARACTERISTICS

Corrosion in the aluminum-magnesium alloys is believed to result from the presence of continuous zones of anodic particles of precipitate at both the grain boundaries and slip planes. The

*Abbreviations used in this text are from the GPO Style Manual, 1967, unless otherwise noted.

magnesium present in excess of that in solid solution forms an aluminum-magnesium compound which is anodic to the aluminum-magnesium solid solution. In a corrosive environment, such as seawater, the anodic compound will suffer accelerated attack. If the anodic constituent is distributed uniformly throughout the microstructure and is present both within the grains and at the grain boundaries, corrosion will not be as severe as when the anodic constituent forms a continuous network at the grain boundaries.

Figure 2 summarizes the three microstructural planes of interest in the 5456-H321 alloy, while Figure 3 presents a composite of these planes superimposed on a small hypothetical block. To facilitate discussion of plate microstructural characteristics, Planes "A," "B," and "C," as illustrated and identified in Figures 1, 2, and 3, will be used.

From Figure 3 it is seen that there are distinct microstructural variations with plate direction. It can also be seen why the short transverse plate orientation is generally considered to be the most susceptible to stress-corrosion cracking. If a specimen is taken in the short transverse (through plate thickness) direction, and Plane "B" OR "A" is stressed in tension, then corrosion may follow the continuous grain boundaries in the longitudinal or long transverse plate directions. On the other hand, if either longitudinal or long transverse specimens are taken out so that Plane "C" is stressed in tension, corrosion following grain boundary paths must continue along a far more discontinuous and tortuous path in the short transverse direction. These discontinuous grain boundary paths provide time for corrosion-stifling polarization to occur, and thus less susceptibility to stress-corrosion cracking is usually observed for the longitudinal and long transverse plate orientations than for the short transverse direction.

STRESS-CORROSION EXPOSURE

None of the 48 specimens tested in this program failed from stress-corrosion cracking during the year of exposure to flowing seawater. When removed from seawater, the specimens were covered with marine fouling, ranging from moderate to severe, as shown in Figure 4. After cleaning, most specimens exhibited only mild general corrosion damage characterized by scattered pitting. Several specimens, however, did suffer accelerated attack.

Figures 5 and 6 illustrate the tension and compression surfaces of the three specimens which suffered the worst attack in this test. On these specimens, pitting had progressed entirely through the 1/16-inch specimen thickness during the year of exposure. From Figure 6 it is evident that some crevice corrosion had also occurred at the specimen ends where contact had been made with the micarta stressing fixtures. Incipient crevice corrosion was also noted on several other specimens. Many specimens showed scattered pitting on the compression face.

MICROSTRUCTURAL CHARACTERISTICS - CORROSION SPECIMENS

In general, pitting susceptibility in the 5456-H321 alloy was nowhere as severe as observed for the wrought, heat-treatable, 7079-T6 alloy.[1] No stress-corrosion cracking was noted from microstructural observations. Slight surface pitting attack was noted on almost all specimens. Upon metallographic examination, pitting attack ranged from complete perforation of 1/16-inch test specimens to moderate surface roughening. No correlation was noted between test stress level and amount or degree of pitting.

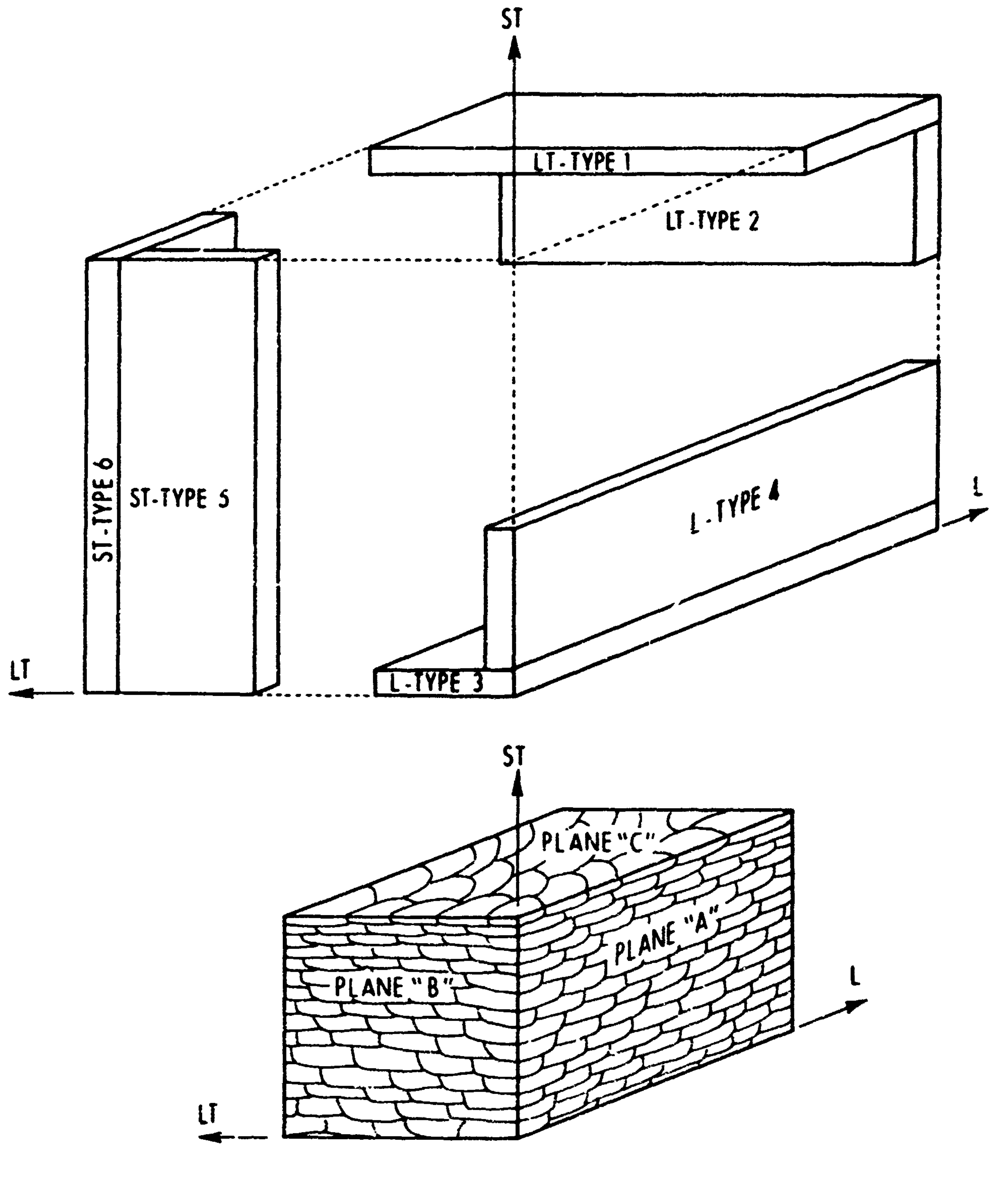
The characteristics and penetration of pitting corrosion appears to be related to plate orientation. Figure 7 shows the "B" microstructural plane of a Type 1 long transverse specimen. With corrosion attack occurring perpendicular to the elongated axes of grains, the pitting is broad and shallow. The same plane, "B," is shown in Figure 8, but representing a cross section of a Type 4 longitudinal specimen. In this case, the direction of attack is parallel to the elongated grain axes, and pitting is deep. Similarly, deep elongated pits occur when the direction of corrosion attack is parallel to the elongated axes of grains in Plane "A," as shown in Figure 9.

It is significant to note that pitting in the three examples cited above developed on the compression side of the specimen. Thus, the pitting is not related to tensile loading. Also significant is the fact that even though the attack is related to grain structure, and the leading edge of attack follows grain boundaries, the metal loss covers a broad area. The broadening of attack, as opposed to its confinement to grain boundary material, is believed to be due to the uniform distribution of the anodic aluminum-magnesium compound throughout the microstructure.

CONCLUSIONS

Aluminum Alloy 5456-H321 is subject to pitting attack in seawater, with the nature of the pitting being related to the characteristic grain structures found in different plate orientations. However, no evidence of susceptibility to stress-corrosion cracking was found in specimens representing various plate orientations when exposed for 1 year in seawater at ambient temperature.

NAVAL SHIP RESEARCH AND DEVELOPMENT CENTER
MARINE ENGINEERING LABORATORY

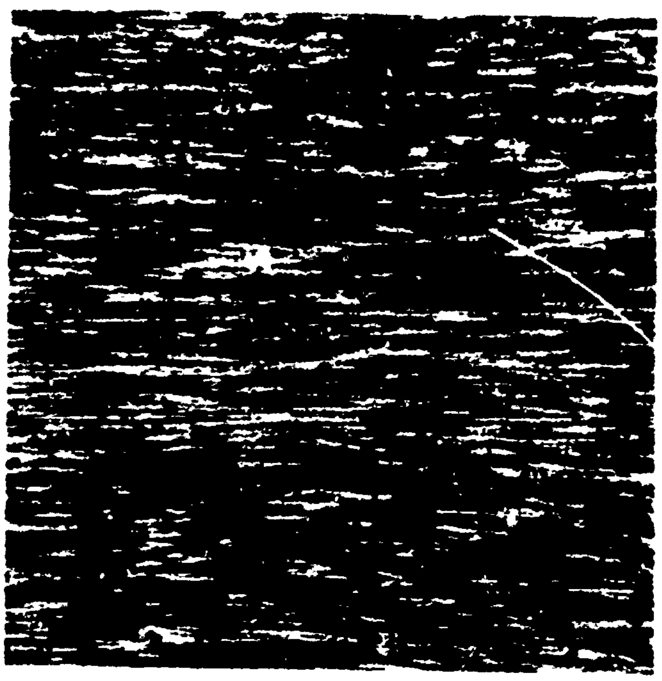


L - Longitudinal
LT - Long Transverse
ST - Short Transverse

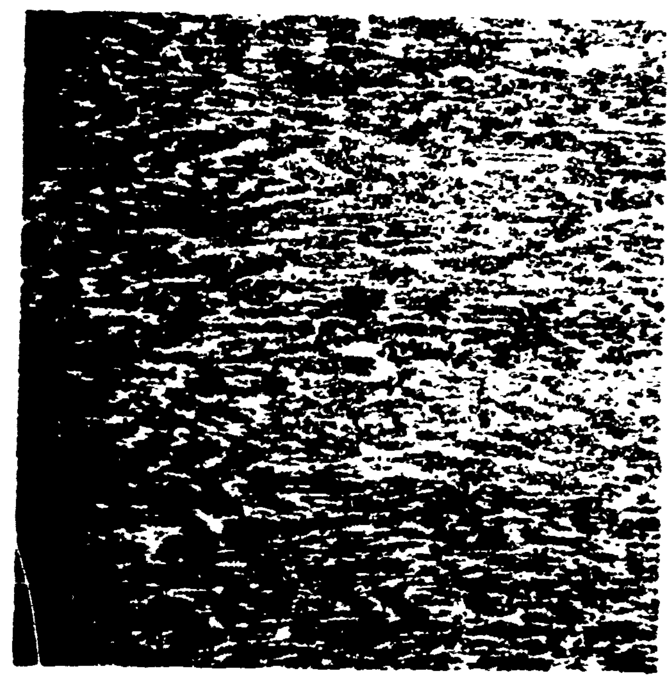
Figure 1
Specimen and Grain Orientations in 5456-H321 Plate

NAVAL SHIP RESEARCH AND DEVELOPMENT CENTER
MARINE ENGINEERING LABORATORY

Plane "A"
Longitudinal/Short-Transverse
Plane



Plane "B"
Long-Transverse/Short-
Transverse Plane



Plane "C"
Longitudinal/Long-Transverse
Plane

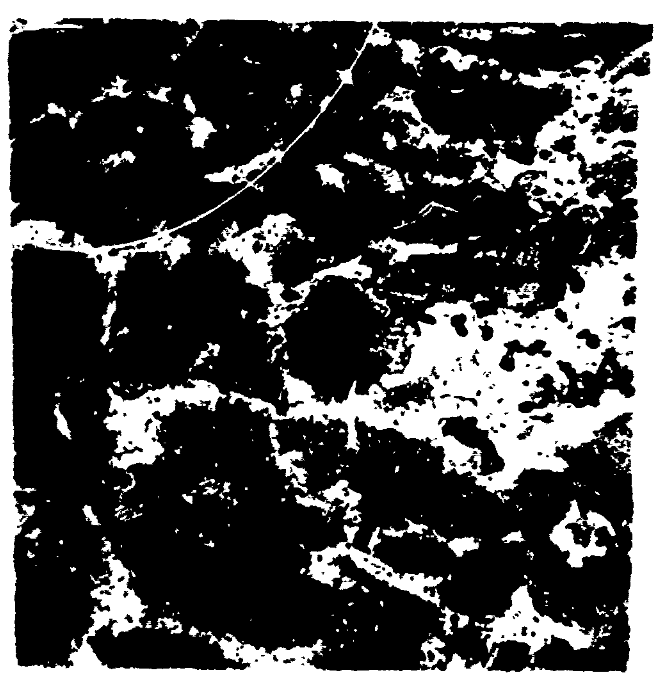
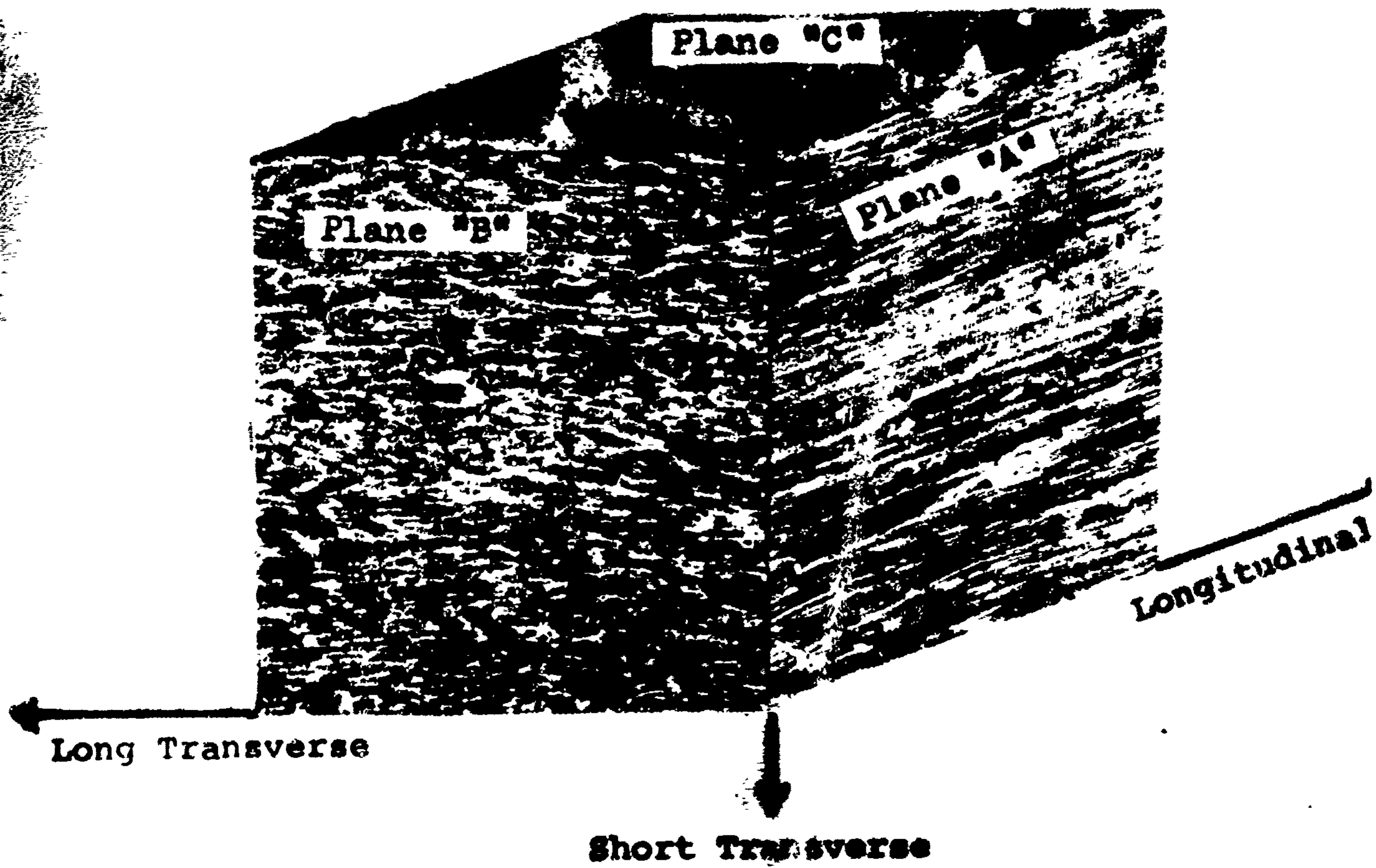


Figure 2 - Photomicrographs Illustrating Variation in Grain Orientation with Plate Direction (100X) (1/2% HF Etch)

Report 2436

NAVAL SHIP RESEARCH AND DEVELOPMENT CENTER

MARINE ENGINEERING LABORATORY

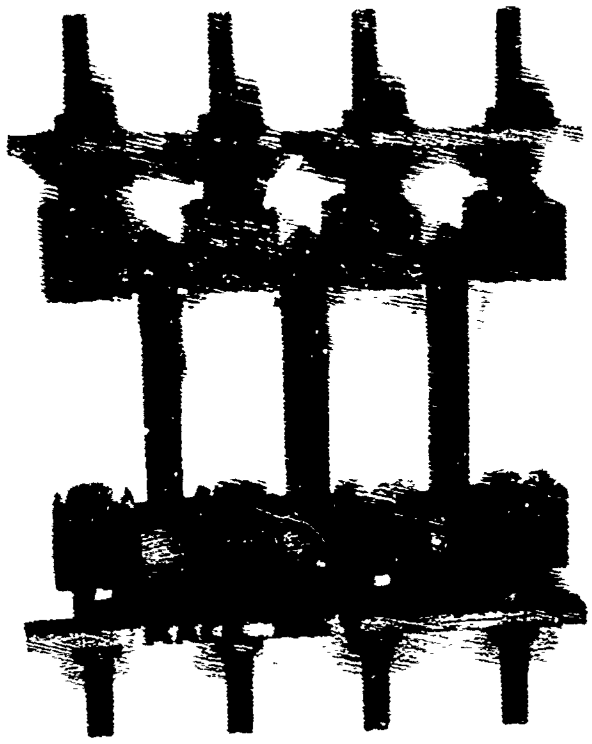


Notes:
Longitudinal/Short Transverse - Plane "A"
Long Transverse/Short Transverse - Plane "B"
Longitudinal/Long Transverse - Plane "C"

Figure 3

Composite Photomicrograph of Grain
Orientation in 5456-H321 Plate
(100X) (1/2% HF Etch)

Prior to Immersion



Exposed for 1 Year in Flowing
Seawater (1-3 fps)

Figure 4 - Appearance of Short Transverse Stress-
Corrosion Specimens After 1 Year of Exposure in Flowing Seawater

NAVAL SHIP RESEARCH AND DEVELOPMENT CENTER

MARINE ENGINEERING LABORATORY

Type 2 Long Transverse	Type 2 Long Transverse	Type 3 Longi-tudinal

Figure 5 - Pitting Attack on Tension Surface of Stress-Corrosion Specimens

Report 2436

NAVAL SHIP RESEARCH AND DEVELOPMENT CENTER

MARINE ENGINEERING LABORATORY

Figure 6 - Pitting and Crevice Attack on Compression Surface of Stress-Corrosion Specimens

NAVAL SHIP RESEARCH AND DEVELOPMENT CENTER

MARINE ENGINEERING LABORATORY

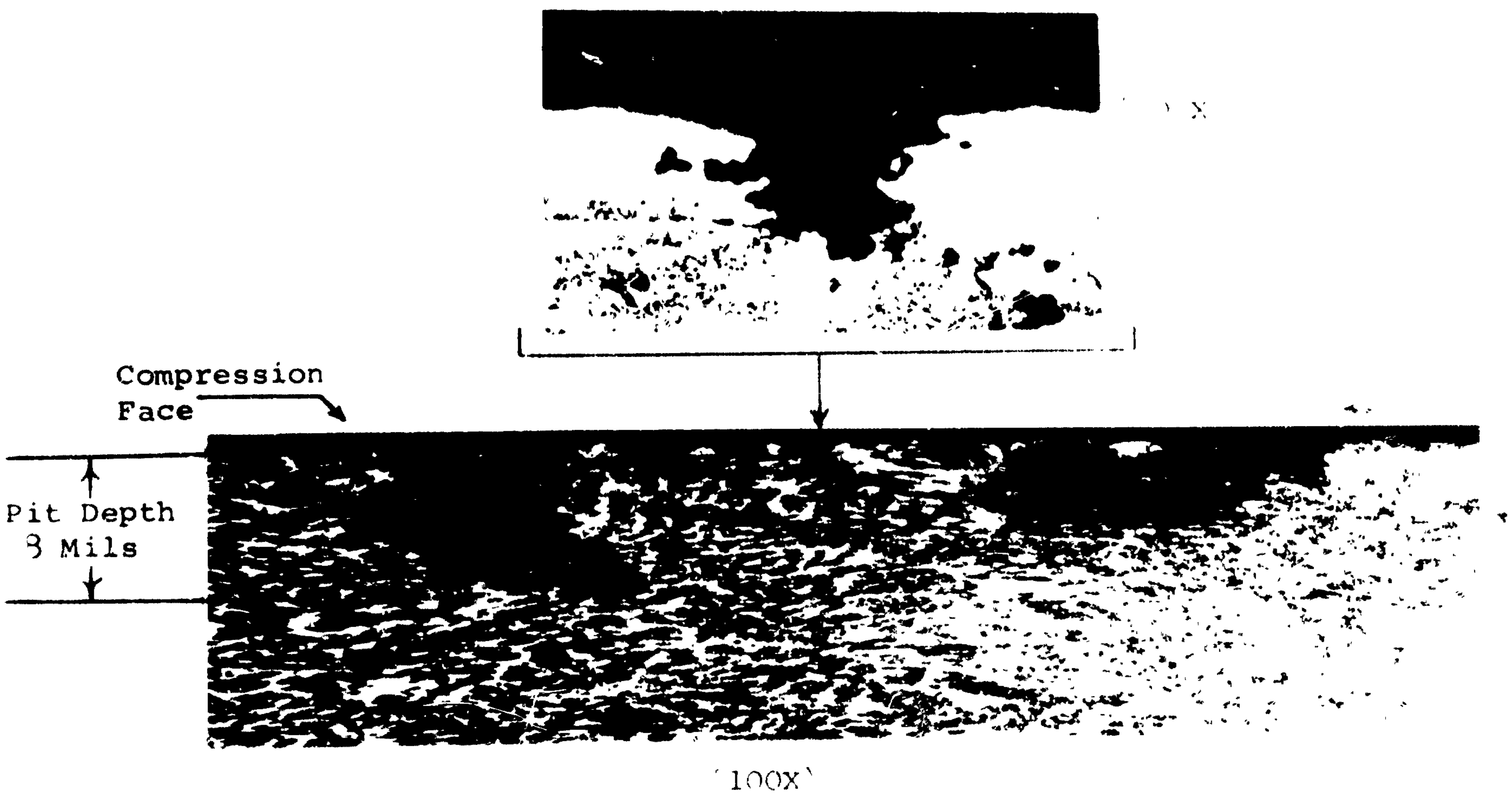


Figure 7

Photomicrographs Illustrating Directionality of Pitting Attack on Plane "F" in Type 1 Long Transverse Specimens (Kellers Etch)

NAVAL SHIP RESEARCH AND DEVELOPMENT CENTER

MARINE ENGINEERING LABORATORY

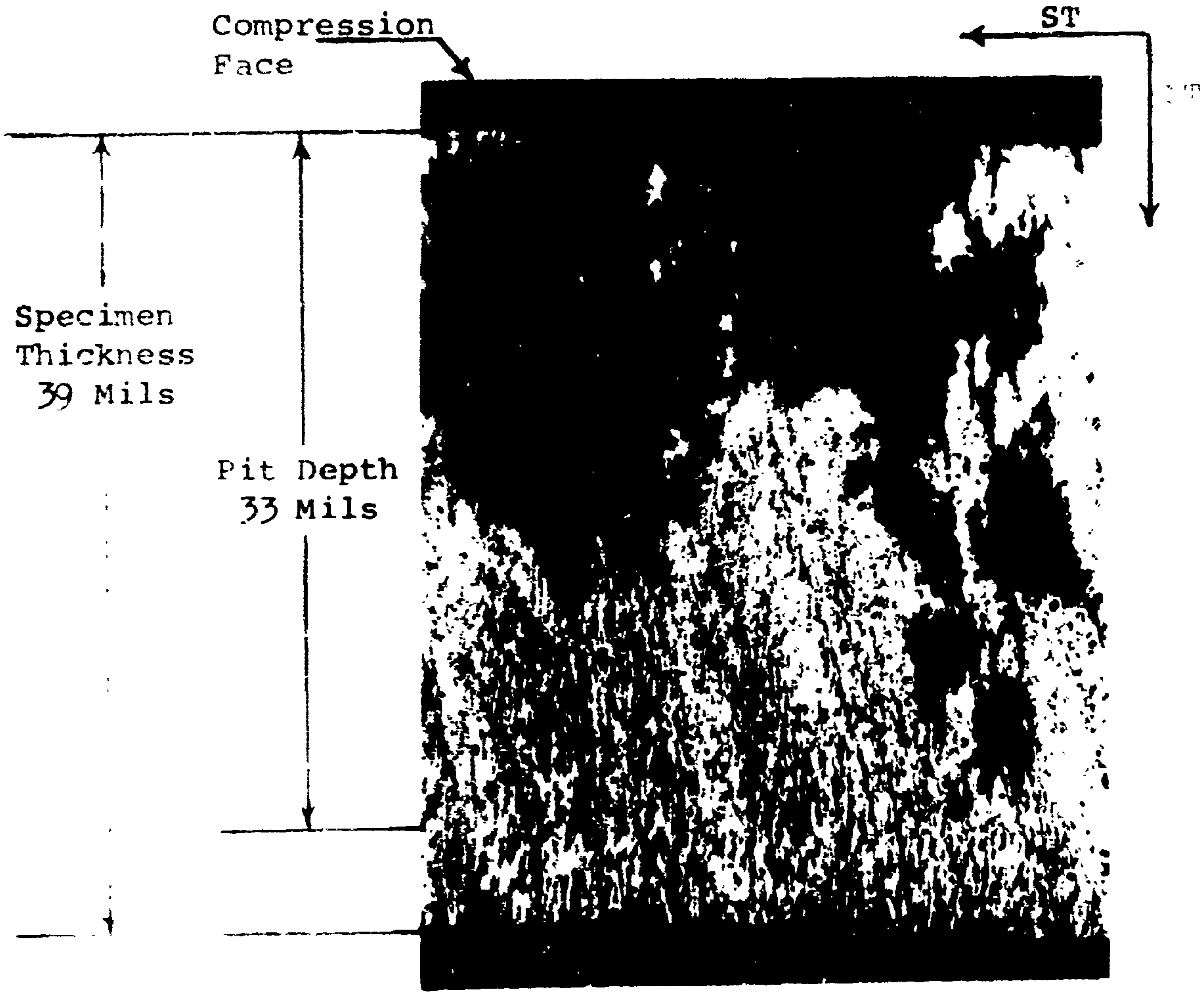


Figure 8

Photomicrograph Illustrating Directionality of Pitting Attack on Plane "B" in Type 4 Longitudinal Specimens (100X) (Kellers Etch)

Report 2436

NAVAL SHIP RESEARCH AND DEVELOPMENT CENTER
MARINE ENGINEERING LABORATORY

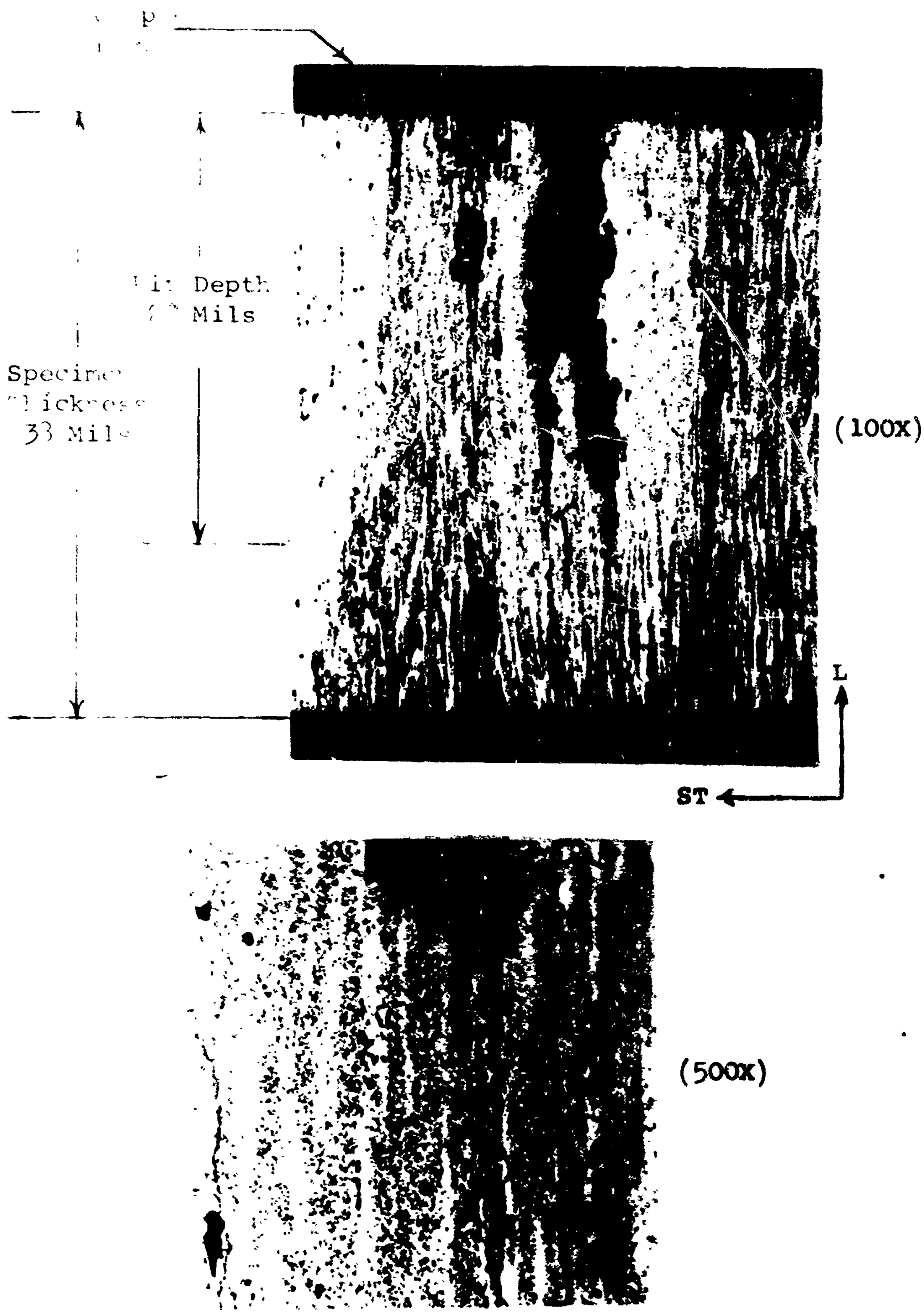


Figure 9 - Photomicrographs Illustrating Directionality of Pitting Attack on Plane "A" in Type 5 Short Transverse Specimens (Kellers Etch)

Appendix A

Technical References

1 - Wacker, G., "Stress-Corrosion Studies of Aluminum Alloy 7079-T6 in Seawater," MEL Rept 444/65, Jan 1966
2 - Thornton, K. F., "Aluminum-Magnesium Alloys Suitable for Structural Welding Applications," Alcoa green ltr, Nov 1957
3 - Spuhler, E. H., and C. L. Burton, "Avoiding Stress-Corrosion Cracking in High Strength Aluminum Alloy Structures," Alcoa green ltr, Aug 1962
4 - "Stress-Corrosion Cracking of Aluminum Alloys," DMIC Memo 202, Feb 1965
5 - Niederberger, R. B., J. L. Basil, and G. T. Bedford, "Corrosion and Stress-Corrosion of 5000 Series Aluminum Alloys in Marine Environment," Corrosion, Vol. 22, Mar 1966
6 - "Stress-Corrosion Cracking of Aluminum Alloys," DMIC Rept 228, Jul 1966
7 - Metals Handbook, Vol. I, 8th Edition, American Society for Metals, 1961

Security Classification UNCLASSIFIED

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) Naval Ship Research and Development Center Annapolis Division Annapolis, Maryland 21402	2a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED
	2b. GROUP

3. REPORT TITLE
Stress-Corrosion Studies of Aluminum Alloy 5456-H321 in Seawater

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

5. AUTHOR(S) (First name, middle initial, last name)
George A. Wacker

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
July 1967	18	7

8a. CONTRACT OR GRANT NO.	9a. ORIGINATOR'S REPORT NUMBER(S) 2436
b. PROJECT NO. S-F020 01 06	
c. Task 0718	9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)
d.	MEL Assigt 86 114

10. DISTRIBUTION STATEMENT
This document has been approved for public release and sale; its distribution is unlimited.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
	NAVSHIPS (SHIPS 0342)

13. ABSTRACT

The stress-corrosion susceptibility of Aluminum Alloy 5456 in the H321 temper was investigated as a function of longitudinal, long transverse, and short transverse plate orientations. The alloy was found to be subject to pitting attack but immune to stress-corrosion cracking in flowing seawater at ambient temperature.

(Author)

Security Classification UNCLASSIFIED

14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Stress corrosion						
Aluminum alloys						
Plate orientations						
Pitting						
Stress-corrosion cracking						
Sea-water environment						
Flowing seawater						
Immunity						
Surface ship application						
Sonar spheres						
Landing pads						
Radar masts						
Small craft						
Hydrofoils						
Surface effect ships (boats)						